Tales of Hoffmann

San Francisco Bay Hydrodynamics

Jacques Offenbach

Producer

Ralph T. Cheng
U. S. Geological Survey
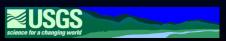Menlo Park, California

Program

Overture:

Review of TRIM family of models

Act I: **San Francisco Bay Nowcast System**

Act II: **SFO runways expansion**

Act III: **Escape from Alcatraz**

Epilog: **Creative Numerical Modeling**

Ralph T. Cheng

USGS
science for a changing world

Overture 🔊: (Introduction)

TALES OF HOFFMANN
BY JACQUES OFFENBACH

Numerical Modeling: Balance Between Science and Technology

"Poet Hoffmann in a beer cellar telling three of his previous love stories"

"Research Hydrologist Ralph Cheng telling three of his recent studies on Hydrodynamics of San Francisco Bay"

Review of TRIM family of models:

Casulli, V., 1990, Semi-implicit Finite-difference Methods for the Two-dimensional Shallow Water Equations, J. Comput. Phys., V. 86, p. 56-74.

Stability Analysis: Gravity wave terms and velocities in Continuity Eq. control the numerical stability

Method of Solution:

1. **Treat those terms implicitly, and the remaining terms explicitly.**

2. **Substituting momentum Eqs. into continuity Eq., resulting a matrix equation that determines the water surface of the entire domain.**

TRIM_2D: Extensive applications in San Francisco Bay

Cheng, R. T., V. Casulli, and J. W. Gartner, 1993, Tidal, residual, intertidal mudflat (TRIM) model and its applications to San Francisco Bay, California, Estuarine, Coastal, and Shelf Science, Vol. 36, p. 235-280.

2D Depth-Averaged Shallow Water Equations

Continuity Eq.:
$$\frac{\partial \varsigma}{\partial t} + \frac{\partial [(h+\varsigma)U]}{\partial x} + \frac{\partial [(h+\varsigma)V]}{\partial y} = 0$$

X-Momentum Eq.:

$$\frac{DU}{Dt} - fV = -g\frac{\partial \varsigma}{\partial x} + \frac{1}{\rho_o(h+\zeta)}(\tau_x^w - \tau_x^b) + A_h\nabla^2 U - \frac{g}{2\rho_o}(h+\varsigma)\frac{\partial \rho}{\partial x}$$

Y-Momentum Eq.:
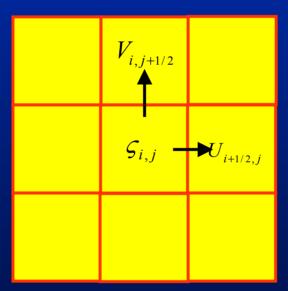
$$\frac{DV}{Dt} + fU = -g\frac{\partial \varsigma}{\partial y} + \frac{1}{\rho_o(h+\zeta)}(\tau_y^w - \tau_y^b) + A_h\nabla^2 V - \frac{g}{2\rho_o}(h+\varsigma)\frac{\partial \rho}{\partial y}$$

X-Momentum Eq.:

$$\frac{DU}{Dt} - fV = -g\frac{\partial \varsigma}{\partial x} + \frac{1}{\rho_o(h+\zeta)}(\tau_x^w - \tau_x^b) + A_h\nabla^2 U - \frac{g}{2\rho_o}(h+\varsigma)\frac{\partial \rho}{\partial x}$$

Semi-implicit FD: Algebraic Eq. of $\varsigma_{i,j}^{n+1}, U_{i+1/2,j}^{n+1}, \varsigma_{i+1,j}^{n+1}$

Total depth is defined on the "side."

Y-Momentum Eq.:

$$\frac{DV}{Dt} + fU = -g\frac{\partial \varsigma}{\partial y} + \frac{1}{\rho_o(h+\zeta)}(\tau_y^w - \tau_y^b) + A_h\nabla^2 V - \frac{g}{2\rho_o}(h+\varsigma)\frac{\partial \rho}{\partial y}$$

Semi-implicit FD: Algebraic Eq. of $\varsigma_{i,j}^{n+1}, V_{i,j+1/2}^{n+1}, \varsigma_{i,j+1}^{n+1}$

Substituting the momemtum Equations into

Continuity Eq.:
$$\frac{\partial \varsigma}{\partial t} + \frac{\partial [(h+\varsigma)U]}{\partial x} + \frac{\partial [(h+\varsigma)V]}{\partial y} = 0$$

$$(1 + A_{i+1,j} + B_{i-1,j} + C_{i,j+1} + D_{i,j-1})\varsigma_{i,j}^{n+1}$$

$$-A_{i+1,j}\varsigma_{i+1,j}^{n+1} - B_{i-1,j}\varsigma_{i-1,j}^{n+1} - C_{i,j+1}\varsigma_{i,j+1}^{n+1} - D_{i,j-1}\varsigma_{i,j-1}^{n+1} = E_{i,j}^{n}$$

With all coefficients are positive.

The governing matrix equation is symmetric, diagonally dominant, and positive definite.

Numerical solution is achieved by a preconditioned conjugate gradient method.

Systematic Development of TRIM Models:

TRIM_3D: Applications in San Francisco Bay and others

Casulli, V. and R. T. Cheng, 1992, Inter. J. for Numer. Methods in Fluids

Casulli, V. and E. Cattani, 1994, Comput. Math. Appl., Stability, accuracy and efficiency analysis of TRIM_3D, θ-method for time-difference

Cheng, R. T. and V. Casulli, 1996, Modeling the Periodic Stratification and Gravitational Circulation in San Francisco Bay, ECM-4.

TRIM_3D: Non-hydrostatic

Casulli, V. and G. S. Stelling, 1996, ECM-4

Casulli, V. and G. S. Stelling, 1998, ASCE, J. of Hydr. Eng

UnTRIM model:

Casulli, V. and P. Zanolli, 1998, A Three-dimensional Semi-implicit Algorithm for Environmental Flows on Unstructured Grids, Proc. of Conf. On Num. Methods for Fluid Dynamics, University of Oxford.
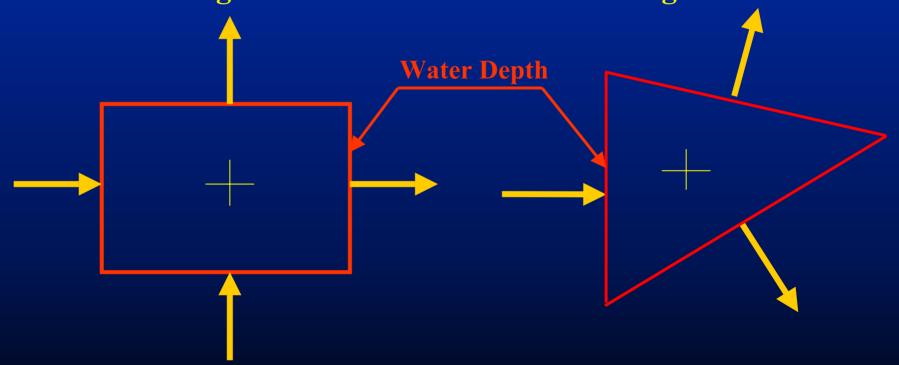
What isTRIM model?

TRIM stands for **T**idal, **R**esidual, **I**nter-tidal **M**udflat

TRIM also implies **simple and elegant** in numerical algorithm and model code, a goal that we are striving for!

From TRIM Series of Models to UnTRIM

1. **Semi-implicit finite-difference of momentum Eq. in the normal direction to each face is applied!**

2. **Applied the Finite-Volume integration of the free surface equation!**
    Local and global conservation of volume is guaranteed!

Water Depth

3. **The resultant matrix equation determines the water surface elevation for the entire field.**

Summary of Numerical Algorithm

Momentum Equation in $\vec{N}_j$ direction for velocity V_j relates

V_j and η (left) and η (right) on each face of a polygon

Continuity and Free-surface Equations

$$Div(\vec{U}) = 0$$

$$\frac{\partial \eta}{\partial t} + \nabla \bullet \left[\int_{-h}^{\eta} \vec{V} \, dz \right] = 0 \qquad \Rightarrow \qquad \frac{\partial \eta}{\partial t} + \oint (\int_{-h}^{\eta} \vec{V} \, dz) \bullet d\vec{s} = 0$$

**Finite Volume integration over each polygon =>
V's are eliminated giving a Matrix Eq. for η**

The continuity equation and the momentum equations are truly coupled in the solution. No mode splitting is used!

Act I

San Francisco Bay

Marine Nowcast System

Tenor: Richard E. Smith

Baritone: Chad English

Conductor: Ralph T. Cheng

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Issues:

Population Growth
Competing Use of Waterway
Increasing Vessel Sizes
Increasing Shipping Traffic
The bottom line:
Protection of Environment &
Improve Navigation Safety!

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Two Standard Oil Tankers Collided in Central Bay, Spilled 800,000 Gal. of Crude Oil January 1971

Ralph T. Cheng

Lighter oil drifts with tidal currents near Golden Gate Bridge, Heavy oil sinks to the bottom and drifts with "Gravitational Residual Current" to upstream!

January 1971

Ralph T. Cheng

Oil-spill incidences are not isolated cases:

Recent Major Oil Spill in San Francisco Bay:

January 1971 --800,000 Gal. Of Crude Oil

November 1984 -- 200,000 Gal. Near Golden Gate Br.

February 1986 -- 28,000 Gal. From a Barge

April 1988 -- 432,000 Gal. Shell's Refinery

October 1996 -- 80,000 Gal. From Dry Dock

Enormous volume of **Crude Oil** is transported through GG (43 % of California's or 5% of US's Oil Consumption)

San Francisco Examiner, Nov. 10, 1996:
"Oil-Spill shows Bay Area can't prevent disaster!"

What we **CAN DO** is to minimize any future damages to the fragile marine ecosystem!

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A Marine Nowcast System for San Francisco Bay, California

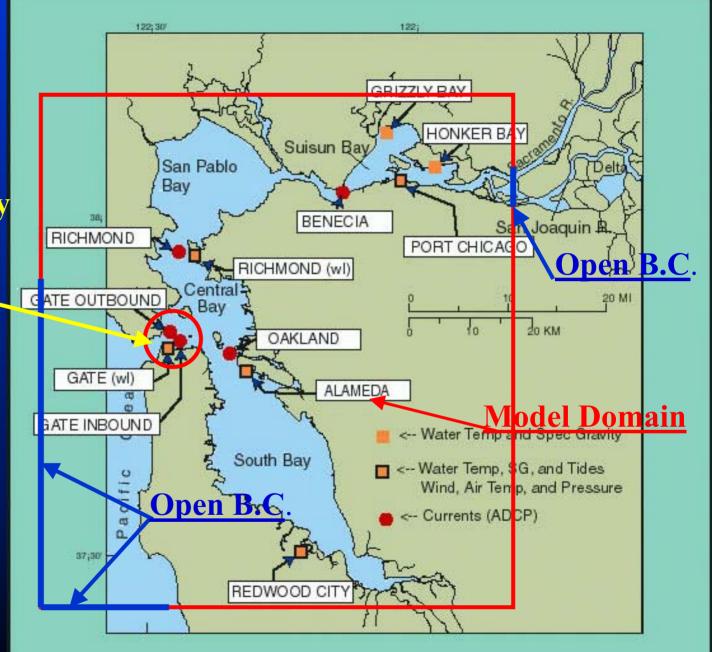## The System -- Integration of Cutting Edge Technologies

- **Real-Time Field Data -- Collaboration with NOS/NOAA <u>PORTS</u> --Physical Oceanographic Real-Time System**

- **Nowcast* Procedures and Nowcast Hydrodynamic Numerical Model (Teaching an Old Dog New Tricks!)**

- **Interpretation and Dissemination of Real-Time Field Data and Nowcast Model Results via WWW**

http://sfports.wr.usgs.gov/sfports.html

*Nowcast: Assimilation procedure to reproduce observations in the immediate past 24 hrs before now, and extending the procedure to predict processes for the next 24 hrs.

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ADCPs data are NOT Available Due to Extremely Harsh Environment

GRIZZLY BAY

HONKER BAY

Suisun Bay

San Pablo Bay

BENECIA

San Joaquin R.

Delta

Sacramento R.

RICHMOND

RICHMOND (wl)

PORT CHICAGO

Open B.C.

Central Bay

OAKLAND

GATE OUTBOUND

0   10   20 MI

0   10   20 KM

GATE (wl)

ALAMEDA

Model Domain

GATE INBOUND

← Water Temp and Spec Gravity

← Water Temp, SG, and Tides Wind, Air Temp, and Pressure

South Bay

Open B.C.

← Currents (ADCP)

Pacific Ocean

REDWOOD CITY

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Concept of Nowcast* Numerical Hydrodynamic Modeling and Data Assimilation

*Nowcast: Assimilation procedure to reproduce observations in the immediate past 24 hrs before now, and extend the procedure to predict processes for the next 24 hrs.

Conventional Modeling Requirements: Bathymetry, Initial and Boundary Conditions, Model Calibration and Validation

Nowcast Objective Kernel is to minimize the difference between the model results and observations in the immediate past 24 hrs.

$$\mathbf{F} = \sum_{i=1}^{M} \int_{t_o}^{t_o+24} \left[\varsigma_i^m(t, P_1, P_2, P_3, ,,, , P_k) - \varsigma_i^o(t) \right]^2 \mathbf{dt} +$$

$$\sum_{j=1}^{N} \int_{t_o}^{t_o+24} \left[V_j^m(t, P_1, P_2, P_3, ,,, , P_k) - V_j^o(t) \right]^2 \mathbf{dt}$$

Ralph T. Cheng

Concept of Nowcast* Numerical Hydrodynamic Modeling and Data Assimilation

The optimization procedure defines the boundary conditions for the next 48 hours of model simulation centered at NOW!

$$\frac{\partial F}{\partial P_k} = 0; \quad k=1,2,3,,,,,,K \quad P_k \text{ are perturbations in B. C.s}$$

The nowcast model is run every hour, continuously and repeatedly starting from 24 hours before now and ending at 24 hours after now.

The Model (Old Dog):

TRIM2D (Cheng, Casulli, and Gartner, 1993)

Grid Size: 378 x 426, $\Delta x = \Delta y = 200$ m on Macator Projection

Total grid pts. = 161,000 ; 48,000 active points.

Computational Efficiency = ~325

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Nowcast Numerical Modeling (Teaching Old Dog New Tricks)

TEACH

Conventional Modeling Requirements

New Tricks

Timing! Timing! Timing!

Home Page of SFPORTS

http://sfports.wr.usgs.gov/sfports.html

Page Title

Agency Logos

Menu

Main Content

Glossary

Go to top

Feedback

San Francisco Physical Oceanographic Real-Time System (SFPORTS)

SFPORTS

Welcome to the
RESEARCH AND DEVELOPMENT PAGE FOR SFPORTS
the production page has moved to ⇒ SFMX

MAKE A SELECTION

- Objectives
- Map of Stations
- Most Recent Data
  - Wind & Tides
  - Currents
  - Current profiles
  - Time-Series
- Model Output
  - Current Maps
  - Forecasts/Animations
  - Time-Series
- Other Resources
- Glossary
- Feedback
- Credits
- Admin/Stats

or

Use a JavaScript
Floating Navigation Window

A partnership of the Marine Exchange of the San Francisco Bay, the California Office of Oil Spill Prevention and Response, NOAA's National Ocean Service, and the U.S. Geological Survey.

The objective of this page is to develop techniques for the delivery of real time oceanographic observations to the maritime community and to investigate the use of numerical hydrodynamic models for forecasting purposes.
Data inputs now include:
Tides (Water Level)
Currents
Winds (see also San Francisco Bay Wind Patterns page)
Water Temperature
Air Temperature
Air Pressure
Short term forecasts of water level and currents
The data available and presentation techniques will continue to expand at this "experimental" site. Once additions are stable and reviewed they will be ported to the production site maintained by the San Francisco Marine Exchange (SFMX).
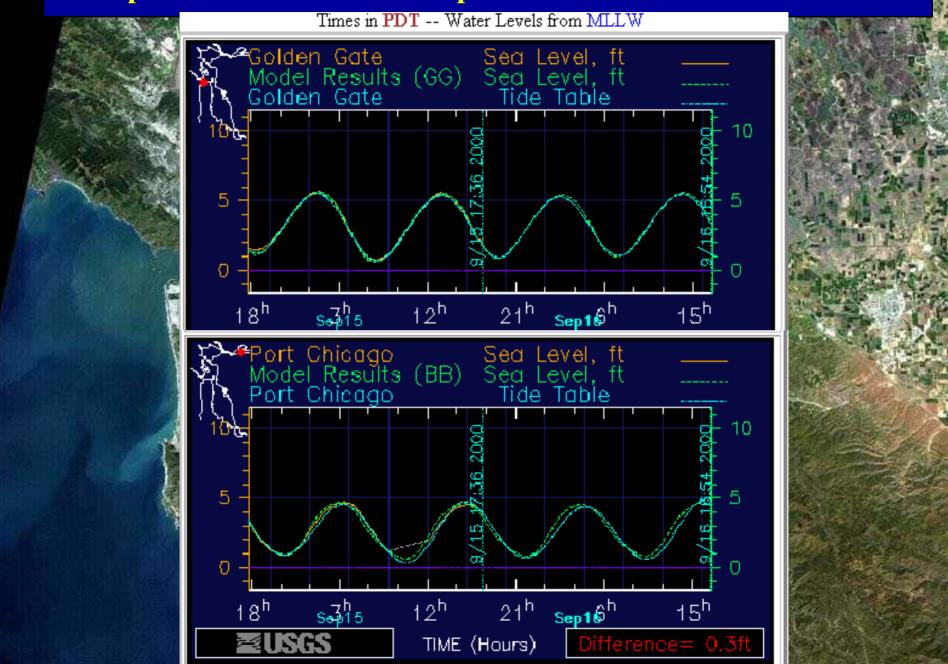Please use the Feedback link to help us improve the data displays and suggest additions.
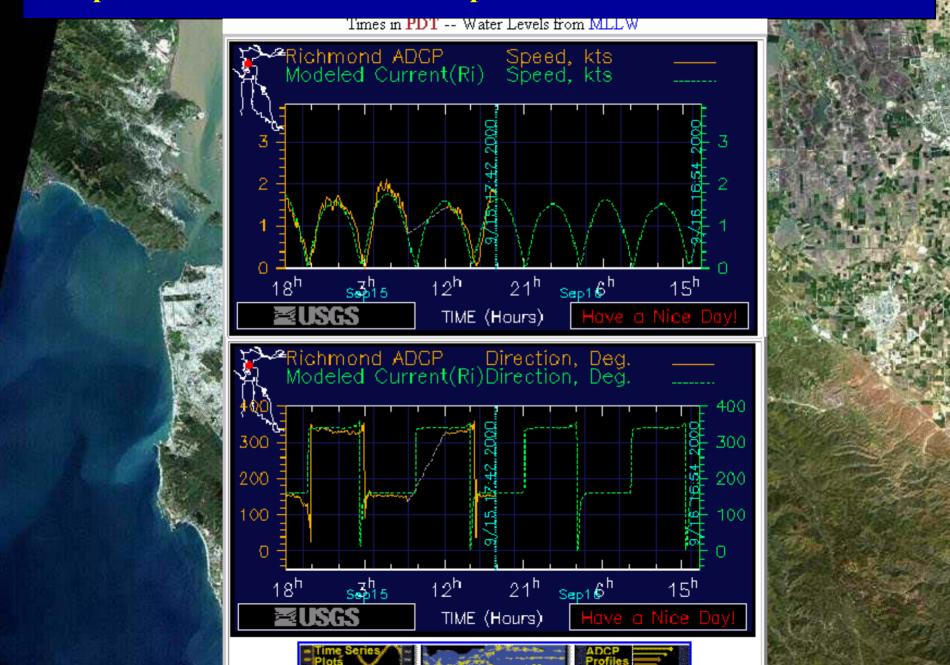
NOAA/NOS SF PORTS Screen Capture (Most Recent Raw Data)
Check out our sister site San Francisco Bay Wind Patterns!

TOP PAGE | GLOSSARY | FEEDBACK

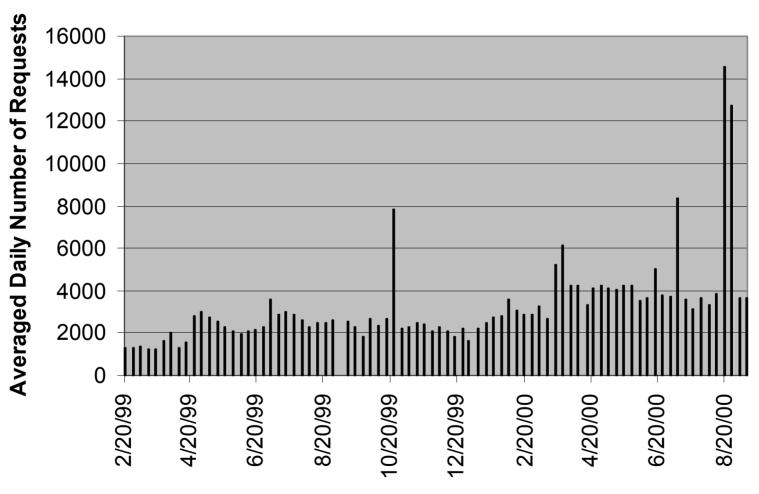# Comparison of modeled and predicted tides with observations

Comparison of Modeled Current Speed & Direction with Observations

Conclusion: When you build it they will come!

SFPORTS WWW Requests

Act II

Strawman's Proposal to Hydrodynamics and Sediment Transport Issues of SFO Runways Expansion

Producer and Conductor:
Ralph T. Cheng

Issues Related to SFO Runway Expansion
> **Hydrodynamics and Sediment Transport**

SFO Runways Expansion:
> **Historical and Philosophical Perspectives**

A Proposed Solution

Conclusion

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OAK

SFO

SJC

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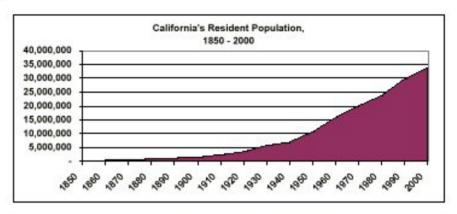
U.S. Census Bureau
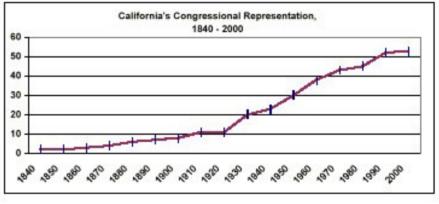
Resident Population and Apportionment of the U.S. House of Representatives

California

Year	Resident Population	Number of Representatives
2000	33,871,648	53
1990	29,760,021	52
1980	23,667,764	45
1970	19,971,069	43
1960	15,717,204	38
1950	10,586,223	30
1940	6,907,387	23
1930	5,677,251	20
1920	3,426,861	11
1910	2,377,549	11
1900	1,485,053	8
1890	1,213,398	7
1880	864,694	6
1870	560,247	4
1860	379,994	3
1850	92,597	2
1840	-	2
1830	-	...
1820	-	...
1810	-	...
1800	-	...
1790	-	...
1789		...

California's Resident Population, 1850 - 2000

California's Congressional Representation, 1840 - 2000

1. The resident population excludes the overseas population.
2. Congressional apportionment for each state is based upon (1) the resident population and (2) the overseas U.S. military and federal civilian employees (and their dependents living with them) allocated to their home state, as reported by the employing federal agencies.

**Estimated Population in the Greater Bay Area:
1930 ~ 1 Million; 1950 ~ 2 Million;
1980 ~ 4 Million; 2000 ~ 6 Million**

Historical and Philosophical Perspectives: 1927 - 2000

First Admin. Bldg Mills Field Municipal Airport of San Francisco (1927)

Mills Field Municipal Airport of San Francisco (1928)

Photos courtesy of SFO Museum

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Historical and Philosophical Perspectives: 1927 - 2000

SFO Expansion Project, 1939

Aerial view of SFO in 1952. Airport expansion in the 50's which has nearly the same configuration as present.

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Photos courtesy of SFO Museum

1952

When?

Year 2000

Historical and Philosophical Perspectives: 1928 - 2000

Life is NOT static!

Changes are necessary to accommodate population and economic growth and to meet the needs of community.

The future changes should be decided by the community!

As members of professional engineering society, our responsibilities are to provide insights and fair evaluations of all proposals, particularly those "outside-of-the-box" ideas, and to formulate a solution that would meet the needs of the community but create least disturbances to the existing ecosystem!

Ralph T. Cheng

Issues Related to SFO Runway Expansion

The propositions:

Population and economic growth, bigger airplanes, new runways are needed to meet the demands

The proposed solution:

"Fill-in" the Bay for runways expansion

The concerns:

Health and well being of S. F. Bay Ecosystem!

Uncertainties in the future!!

The bottom line:

Can we accommodate runways expansion and preserve the ecosystem at "Status Quo"?

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Issues Related to SFO Runway Expansion

"Fill-in" the Bay for runways expansion

Questions:

1. Will "fill-in" affect the Hydrodynamics and Sediment Transport?

2. Can we define the regions of influence? Local, regional, or bay-wide?

3. Is there a solution that can accommodate runways expansion AND preserve the hydrodynamics at "Status Quo"?

(Hydrodynamics and Sediment Transport)

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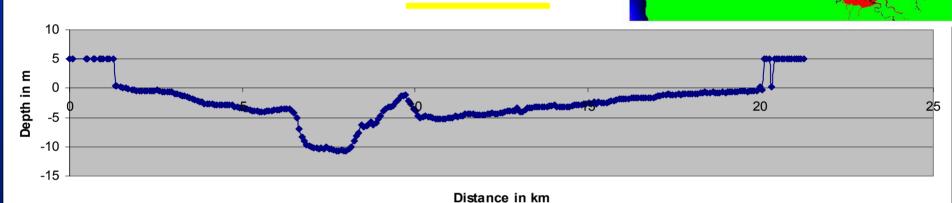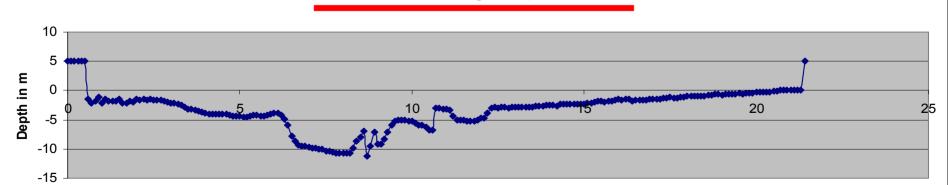
Geometrical considerations:

X-sections

SFO to San Leandro
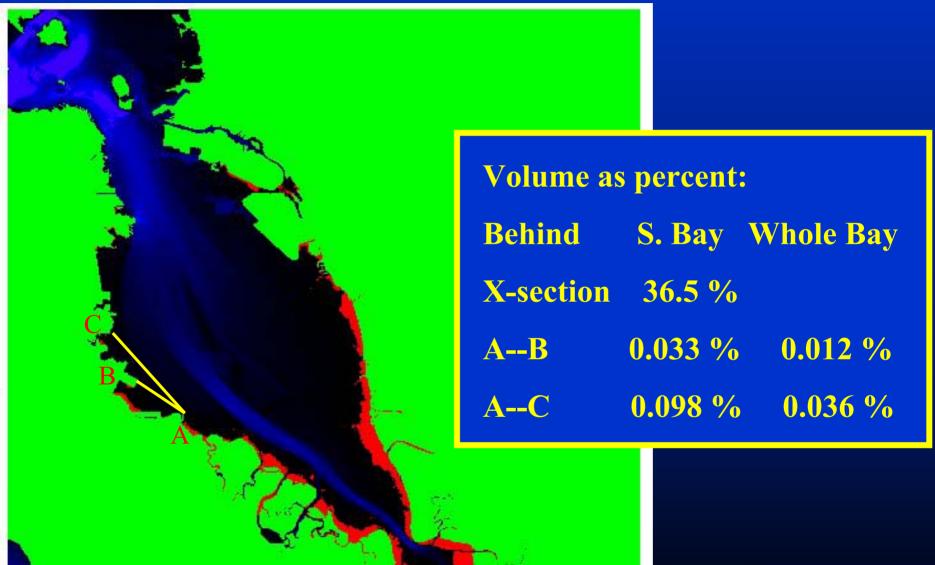
East-West Cut through Seaplane Harbor

Ralph T. Cheng
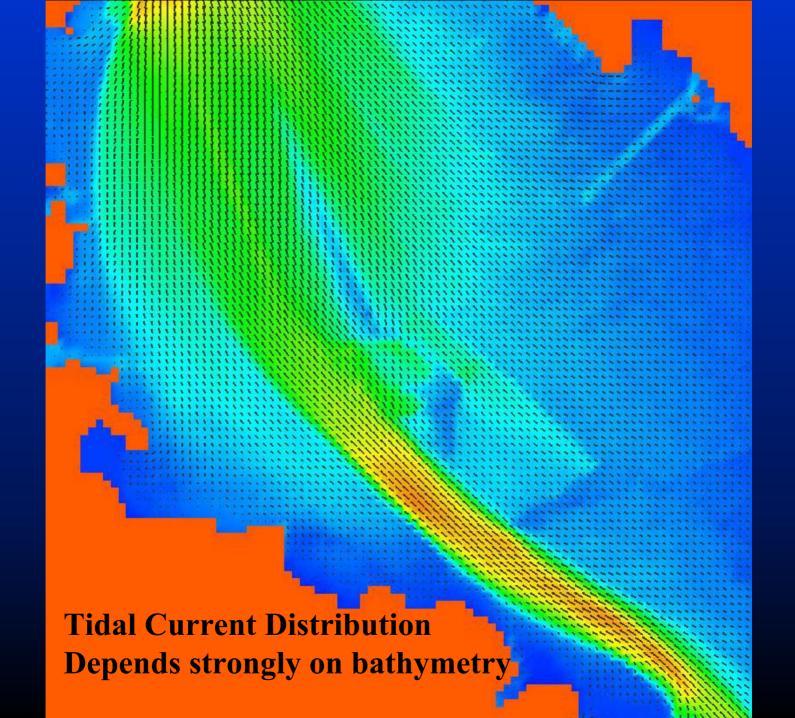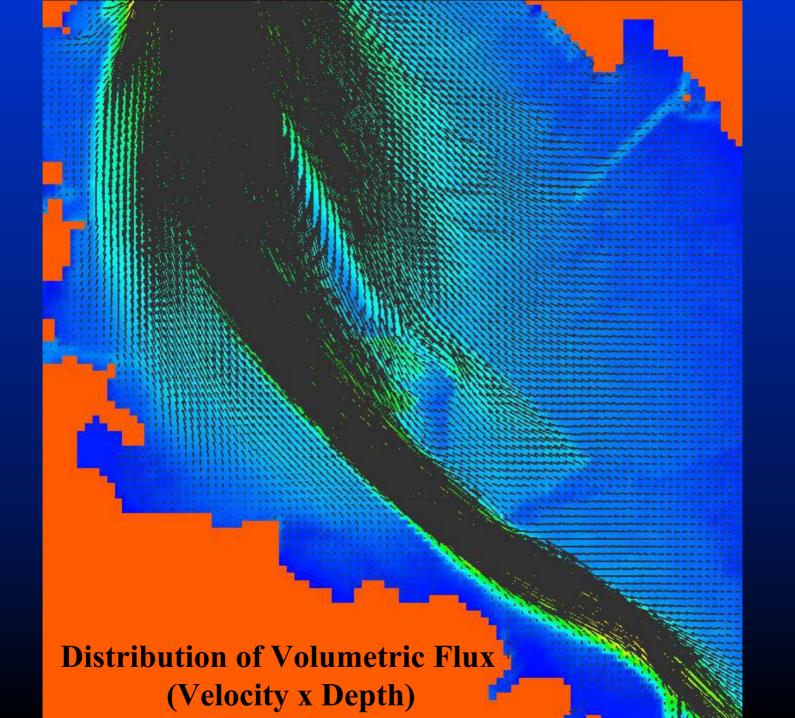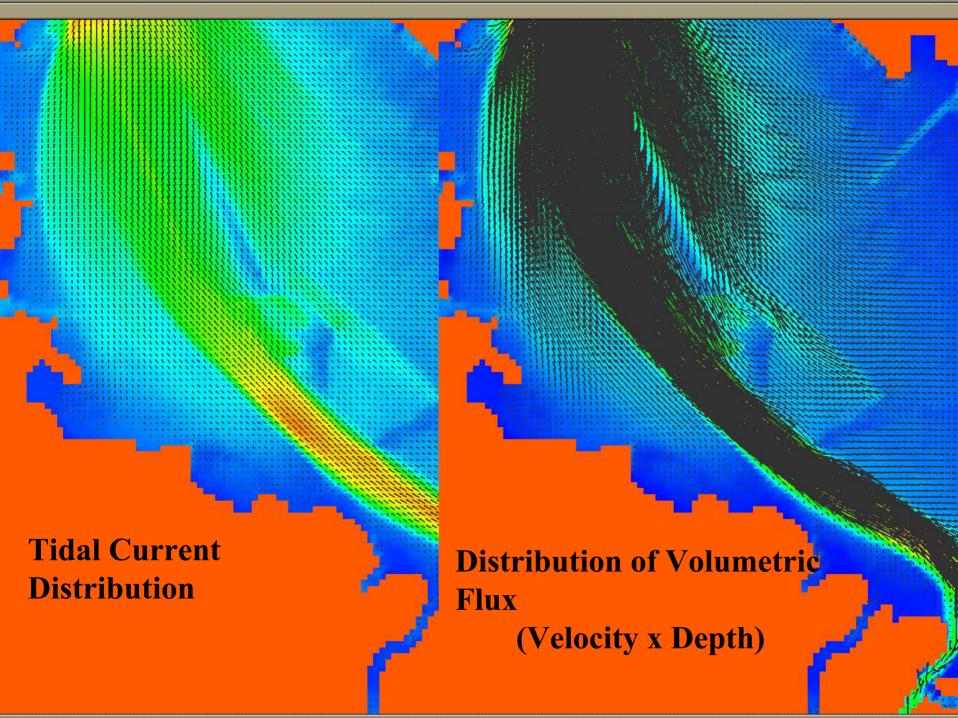
Geometrical Considerations: VOLUME

Volume as percent:

Behind	S. Bay	Whole Bay
X-section	36.5 %	
A--B	0.033 %	0.012 %
A--C	0.098 %	0.036 %

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**Tidal Current Distribution
Depends strongly on bathymetry**

Distribution of Volumetric Flux (Velocity x Depth)

Tidal Current Distribution

Distribution of Volumetric Flux

(Velocity x Depth)
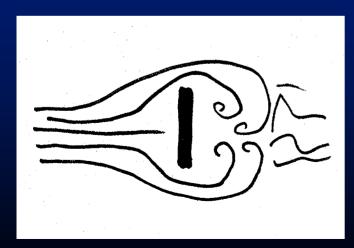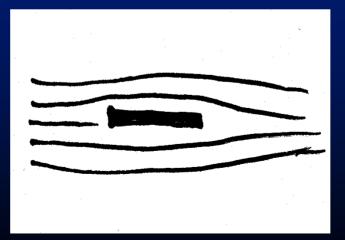
A Proposed Solution:

Objectives: To accommodate runway expansion and keep the changes to the circulation and sediment movements to minimal

Solution based on simple hydrodynamics: Build a <u>streamlined</u> "retention-wall" enclosure of runways expansion.

Blunt Object

Smooth Object

Ralph T. Cheng

A Proposed Solution:
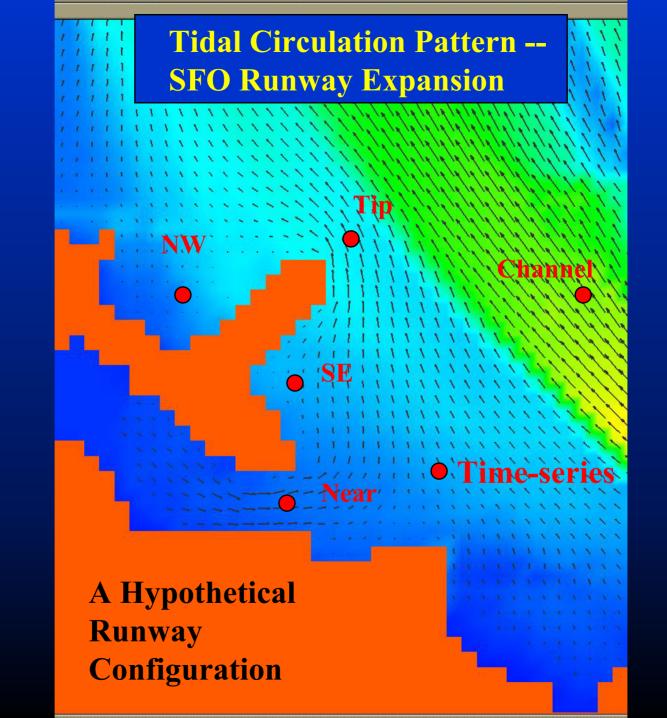
Objectives: To accommodate runways expansion and also keep the changes to the circulation in the Bay and sediment movements to a minimum.

Simple Hydrodynamic Principles:
   Build a <u>streamlined</u> "Retention-wall" enclosure of runway expansion.
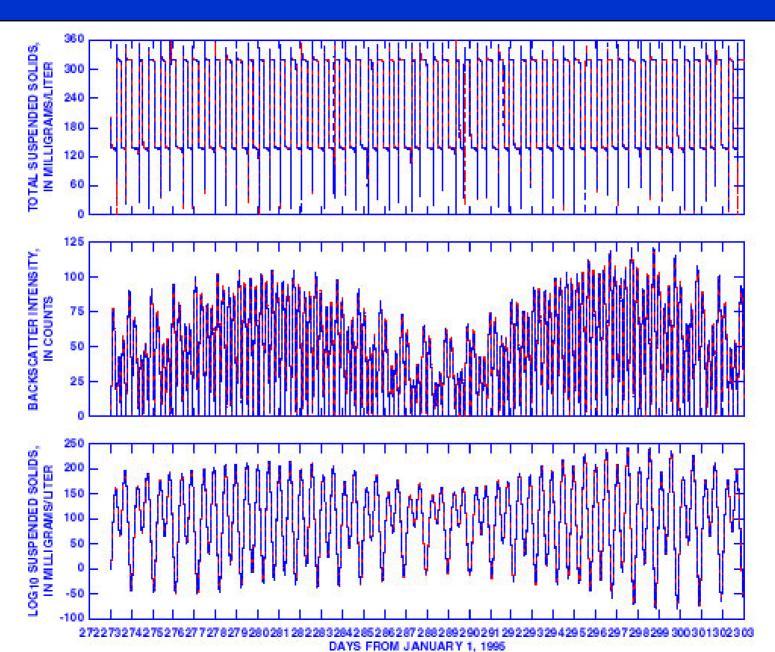
Numerical Model of three scenarios:
1. **Present Condition**
2. **Runway Expansion**
3. **Retention-wall Enclosure**

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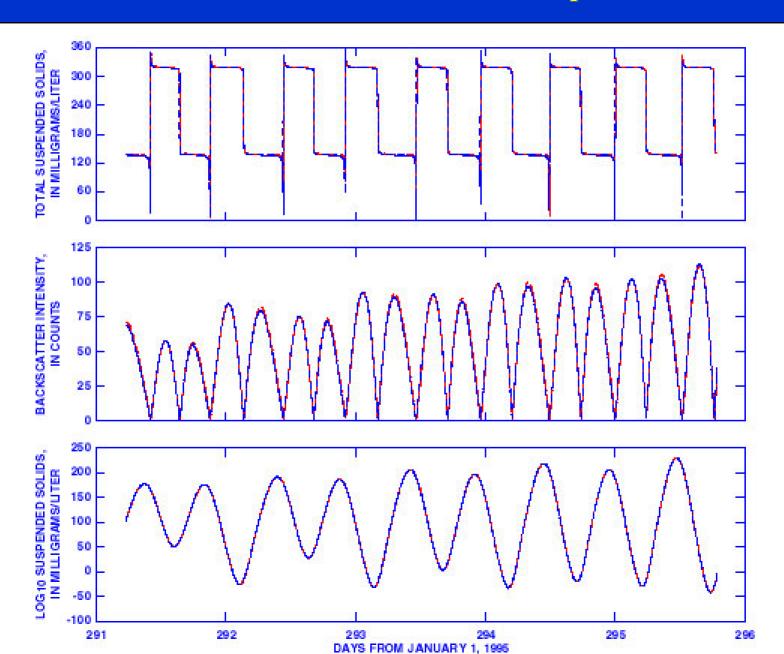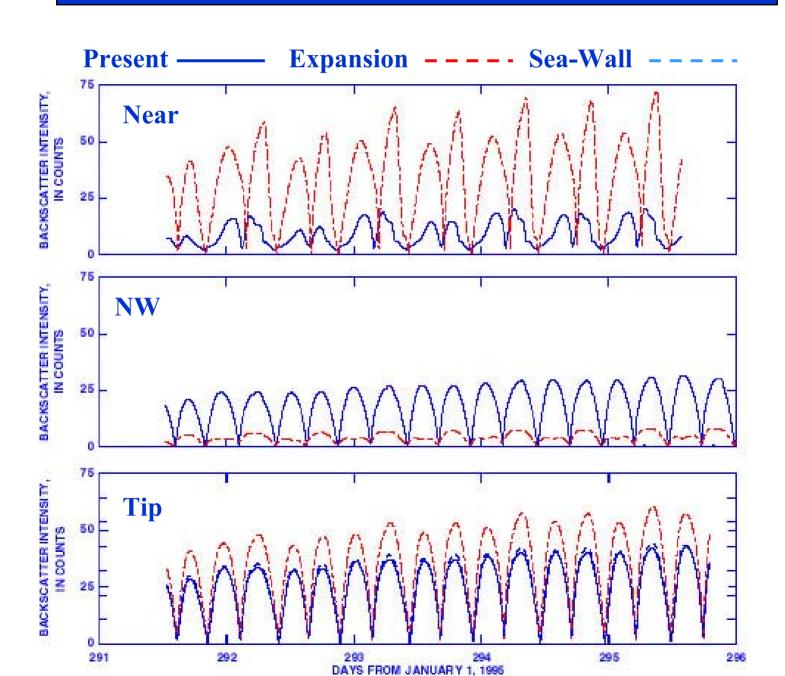
Time-series saved in the channel for Present, Expansion, and Wall
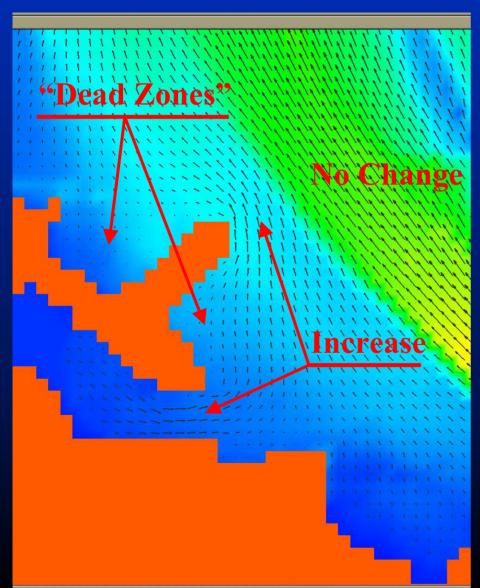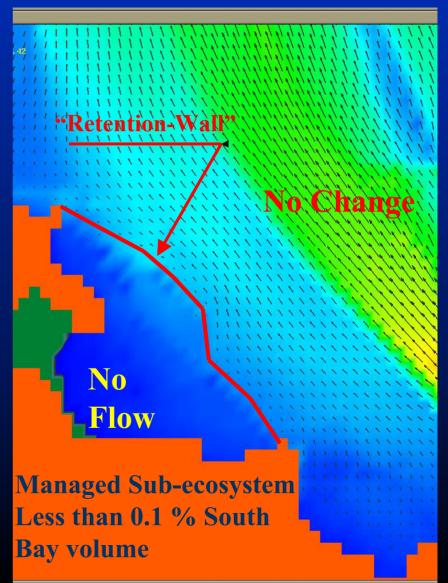
Time-series saved in at "Near", "NW", and "Tip"

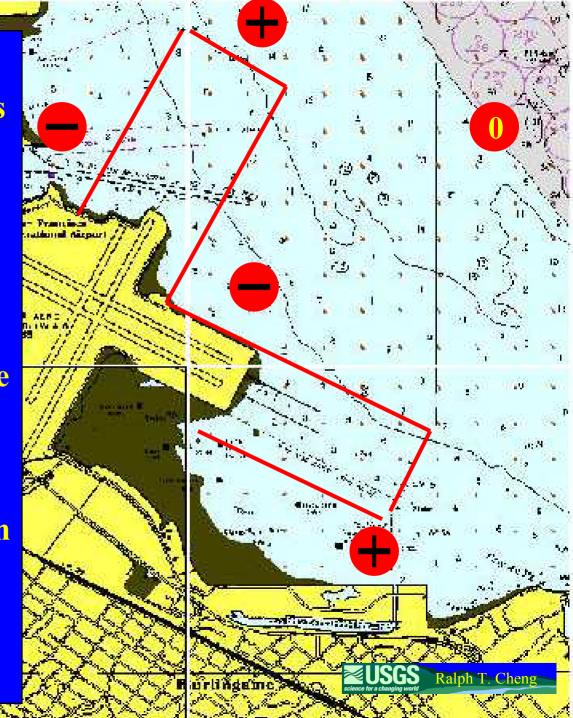# Numerical Model Simulation of Tidal Circulation Pattern

SFO Runway Expansion

Sea-Wall Enclosure

Conclusions:

1. **Life is not static, changes are necessary to meet the needs of society.**
2. **Tools are available for assessing impacts due to SFO runway expansion.**
3. **This strawman proposal illustrates that it might be possible to formulate solutions that can minimize the impacts due to runways expansion**
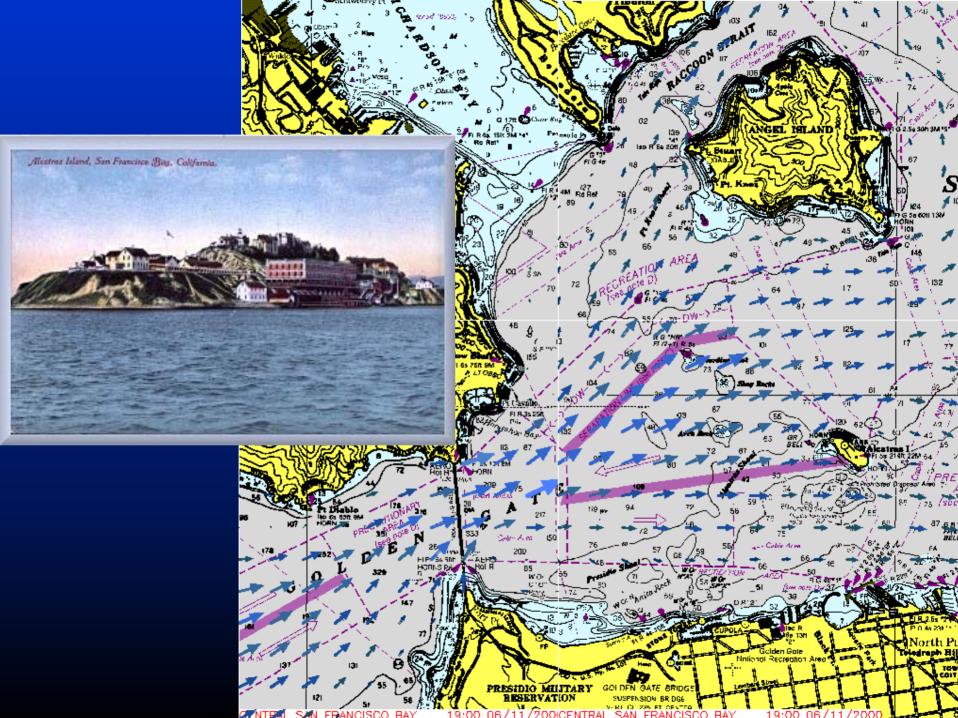4. **Need more *creative* research to formulate an engineering solution.**

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Act III

Escape from Alcatraz

Conductor: Ralph T. Cheng

Producer: Discovery Channel

Alcatraz Island, San Francisco Bay, California.
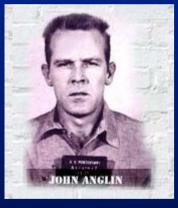
Discovery Channel: Escape No.13: June 11, 1962

Frank Lee Morris, Age 35

Highly intelligent, IQ 133

Bank Burglary, Escape record

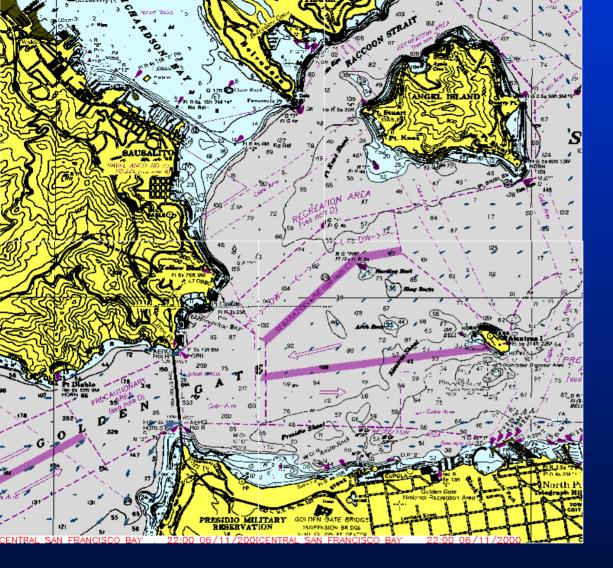**John Anglin, Age 32**

Bank Robbery, Escape record

Clarence Anglin, Age 31

Bank Robbery, Escape record

Alcatraz was a jail for most notorious prisoners!
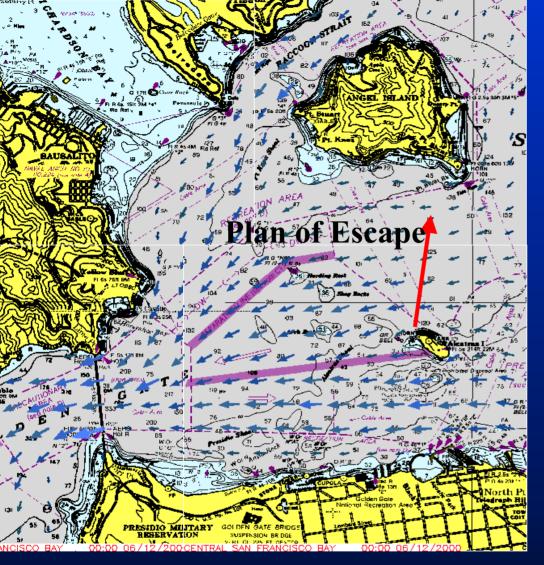
Known Facts:

June 11, 1962

Last seen around 9:00 PM

Their disappearance was discovered at 7:00 AM June 12, 1962

Estimated escape time:

10:00 or 11:00 PM June 11, 1962

Simulated Tidal circulation @ 10:00 PM, June 11, 1962
Estimated water temperature ~ 51 or 53° F
Wind was 15~16 knots from WSW

Plan of Escape

Original plan was to swim to Angel Island.

Some belongings were found in the bay.

FBI case is still open, the prisoners are presumed drown, but none of the 3 bodies were every found.

Simulated Tidal circulation @ 12:00 AM, June 11, 1962
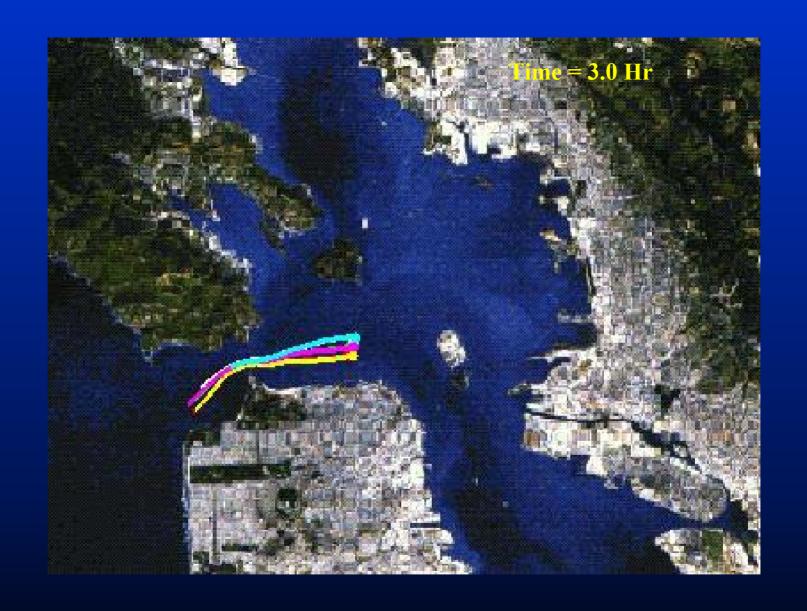Estimated water temperature ~ 51 or 53º F
Wind was 15~16 knots from WSW

Numerical Simulation of Lagrangian drifters
Starting time: 10:00 PM June 11, 1962

Time = 1.0 Hr.

Numerical Simulation of Lagrangian drifters
Starting time: 10:00 PM June 11, 1962

Numerical Simulation of Lagrangian drifters
Starting time: 10:00 PM June 11, 1962

Time = 3.0 Hr

Numerical Simulation of Lagrangian drifters
Starting time: 10:00 PM June 11, 1962

Observations:

1. Numerical model shows the drifters could reach areas near Golden Gate Bridge in about 2 hours!

2. If the 3-prisoners only swam **across** the current, they could reach either San Francisco or Marine County shore in ~2 or 2 ½ Hrs.

3. None of 3-prisoners were ever seen again, live or dead!

Factors to consider:

1. Could these "young" men survive the cold Bay water temperature for ~2 to 3 Hrs.?

2. Did they change from their original escape plan?

3. The official position: They are presumed drown, but the FBI case is still open!

4. Their bodies were never found.

Question:
What is the fate of these three escapees?
A. Drown   B. Escaped

Factors to consider:

1. Could these "young" men survive the cold Bay water temperature for ~2 to 3 Hrs.?

2. Did they change from their original escape plan?

3. The official position: They are presumed drown, but the FBI case is still open!

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Question:
What is the fate of these three escapees?
    A. Drown (40%) B. Escaped (60%)

Epilog:

Summary

Three examples are used to demonstrate the balance between science and technology. Basic process oriented research (science) builds tools (models) that were used creatively to solve interesting hydrodynamic problems in San Francisco Bay.

Other observations:

Physics and Numerical methods are intertwined; better understanding the physical processes leads to successful modeling tasks.

Numerical modeling is not just solving the governing equations, creativity is an essential element.

Issues Related to SFO Runway Expansion

The proposition:

　　Population growth in this region, additional
　　runways are needed to meet the demands

The proposed solution:

　　"Fill-in" the Bay for runways expansion

The concerns:

　　Health and well being of S. F. Bay Ecosystem

　　Can we build the runways and preserved the
　　at Bay system at present "Status Quo"?

(Hydrodynamics and Sediment Transport)

Ralph T. Cheng

Two Scenarios of HazMat Responses:

1. **Response at a remote site;**
   Not much prior hydraulic, oceanographic,
   and meteorological data are available.

2. **At major ports and harbors, construct marine nowcast systems BEFORE any major accident takes place.**

Who are the players:

NOS/NOAA

USGS

S.F. Marine Exchange

OSRP, Fish & Game, CA

Who are the users:

Navigation Safety Authorities

Ship Skippers and Pilots

Environment Protection Organizations

Oil-Spill Response and Planning

HazMat Cleanup

Scientists and Recreational users

USGS
science for a changing world   Ralph T. Cheng